

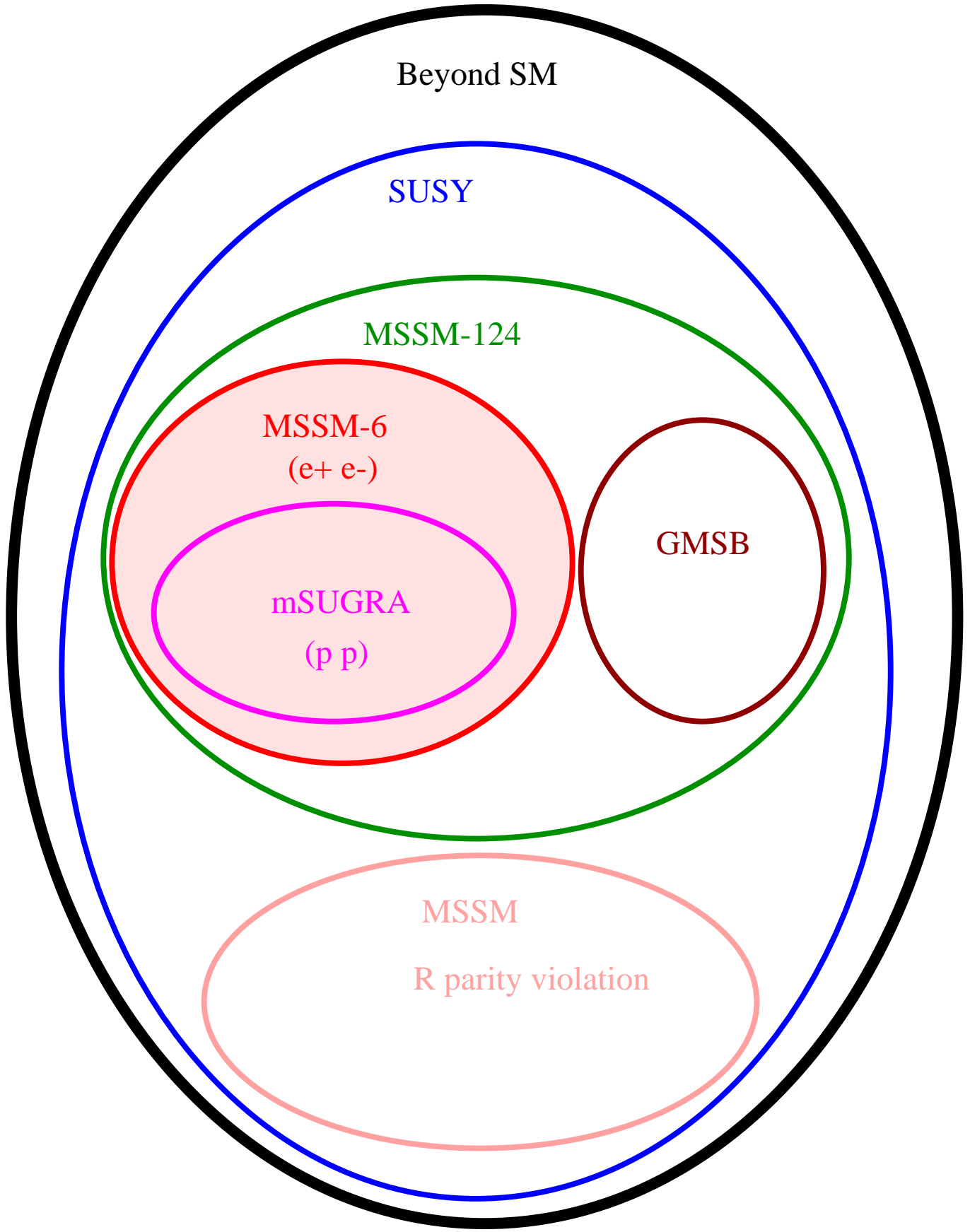
SUSY Searches at LEP

Thomas Hebbeker
Humboldt University Berlin

Beyond the Desert
Ringberg Castle
June 1999

Outline:

- SUSY Framework
- LEP
- Searches:
 - Sneutrino
 - Smuon
 - Stop
 - Charginos
 - Neutralinos
- SUSY Limits



Beyond SM

SUSY

MSSM-124

MSSM-6
(e+ e-)

mSUGRA
(p p)

GMSB

MSSM
R parity violation

MSSM-6 = CMSSM

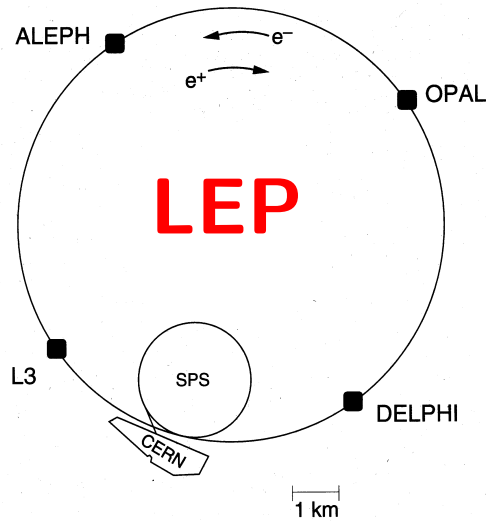
Assumptions:

GUT, no CP violation, generation-independence . . .
R parity conserved!

Parameters:

- $m_0 =$ Universal scalar mass at GUT scale
0 . . . ≈ 2000 GeV
- $M_2 = SU(2)$ Gaugino mass at electroweak scale
0 . . . ≈ 2000 GeV
- $\mu =$ Higgs mass parameter (elw)
 ≈ -2000 . . . ≈ 2000 GeV
- $\tan \beta =$ ratio of vacuum expectation values (elw)
1 . . . ≈ 50
- $A_0 =$ Universal trilinear couplings (GUT)
0 . . . ≈ 2000 GeV (sfermion mixing)
- $m_A =$ Physical mass of CP-odd Higgs
0 . . . ≈ 2000 GeV (higgs masses)

Additional requirement: LSP (Lightest Susy Particle)
has no electromagnetic or strong interaction
(cosmology) $\rightarrow \tilde{\chi}, \tilde{\nu}$



LEP 1:

1989 - 1995

$\sqrt{s} \approx 91 \text{ GeV}$

$L = 160 \text{ pb}^{-1} / \text{experiment}$

Advantages:

- Xsection high
- Z (invisible) width: limits independent of decay mode

LEP 2:

1996 - 2000

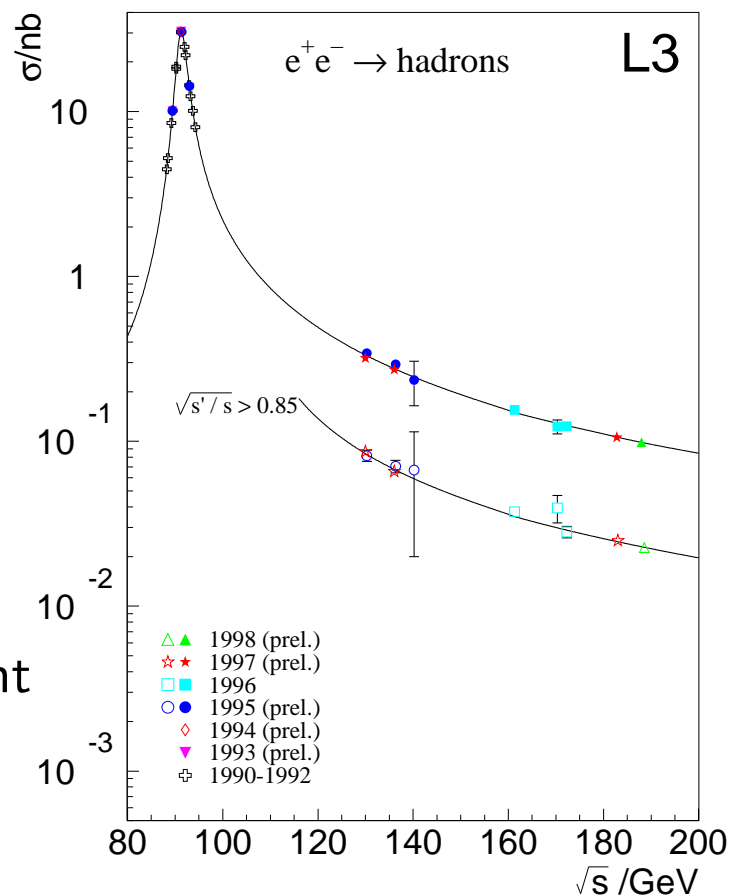
$\sqrt{s} = 160 - 200 \text{ GeV}$

$L = 260 \text{ pb}^{-1} / \text{experiment}$

in 1996-1998

Advantages:

- Center of mass energy large



MSSM-6 Searches at LEP

Squarks $\tilde{u}, \tilde{d}, \tilde{s}, \tilde{c}$ and Gluinos \tilde{g} are heavy \rightarrow Tevatron !

LEP:

- Sneutrino $\tilde{\nu}$
all three families mass degenerate
- Smuon $\tilde{\mu}$
representative for $\tilde{e}, \tilde{\mu}, \tilde{\tau}$
- Stop \tilde{t}
representative for \tilde{b}, \tilde{t}
for heavy quarks mixing possibly large and \tilde{t}_1 light:

$$\tilde{t}_L \quad \tilde{t}_R \quad \rightarrow \quad \tilde{t}_1 \quad \tilde{t}_2$$

- Charginos $\chi_1^\pm < \chi_2^\pm$
- Neutralinos $\chi_1^0 < \chi_2^0 < \chi_3^0 < \chi_4^0$
 χ_1^0 is favorite LSP candidate

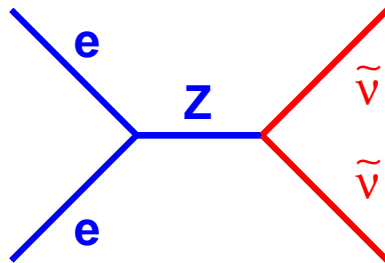
SIGNATURE: Missing energy and momentum

Also: MSSM-Higgs searches at LEP
(see previous talks)

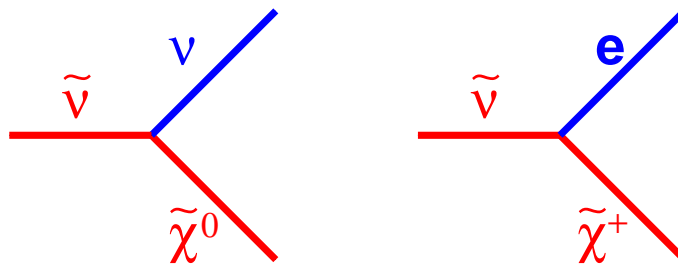
Sneutrino

3 families degenerate!

PRODUCTION:



Sneutrino can be stable or might DECAY:



In both cases missing energy in the final state!

Limit from invisible Z width measured at LEP I:

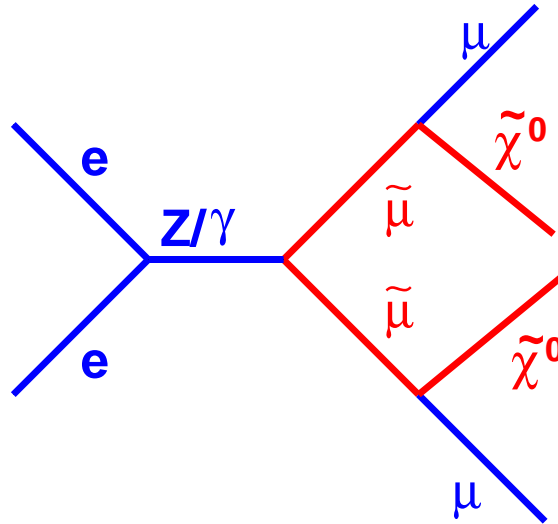
$$\Gamma_{\text{inv}} < 2.8 \text{ MeV} \quad 95\% \text{ CL}$$

RESULT ('indirect' limit):

$$m > 43 \text{ GeV} \quad 95\% \text{ CL}$$

Smuon

PRODUCTION and DECAY:



SIGNATURE:

Two acollinear muons

BACKGROUNDS:

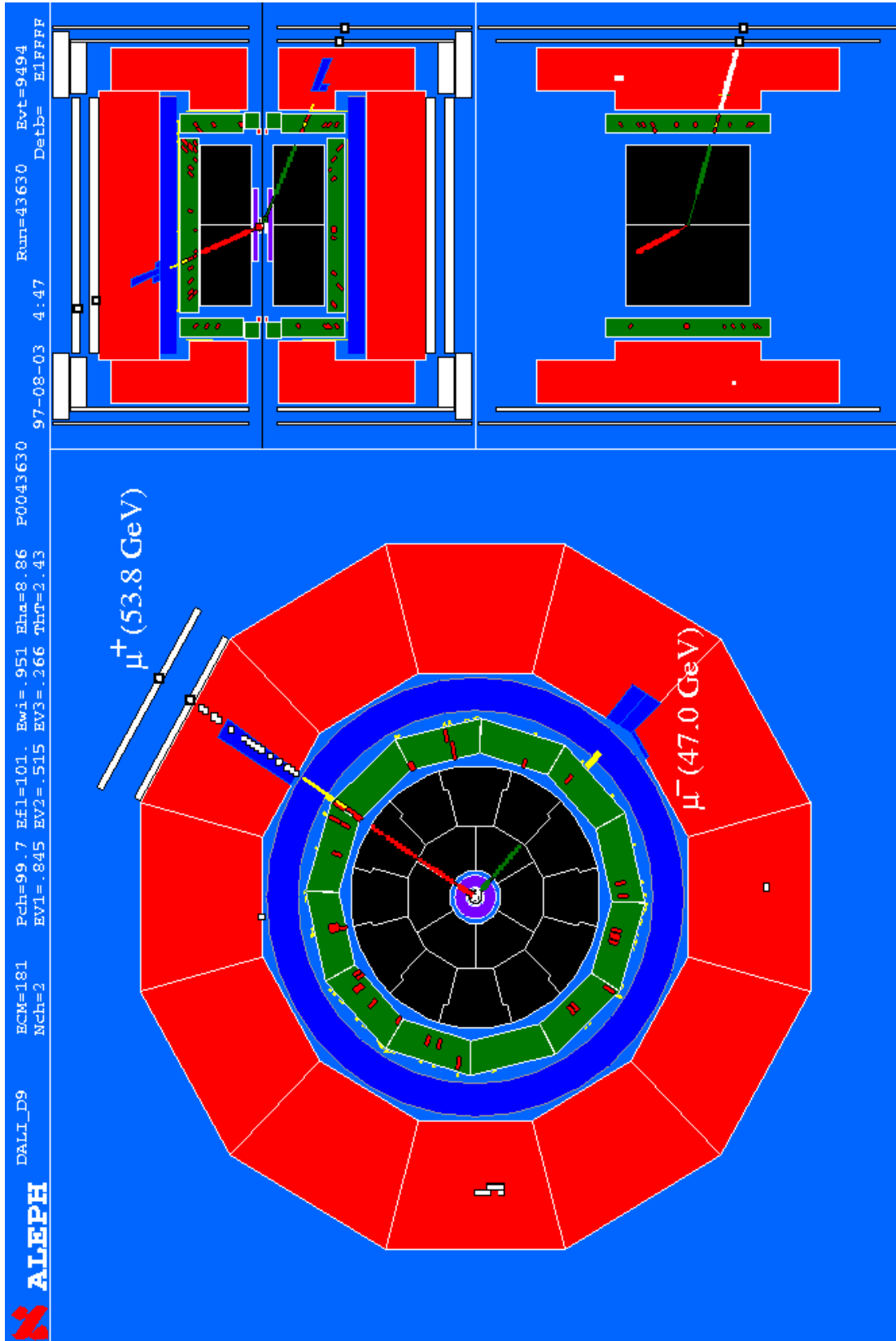
'two photon': $e^+e^- \mu^+ \mu^-$, W pairs: $W^+W^- \dots$

REMARKS:

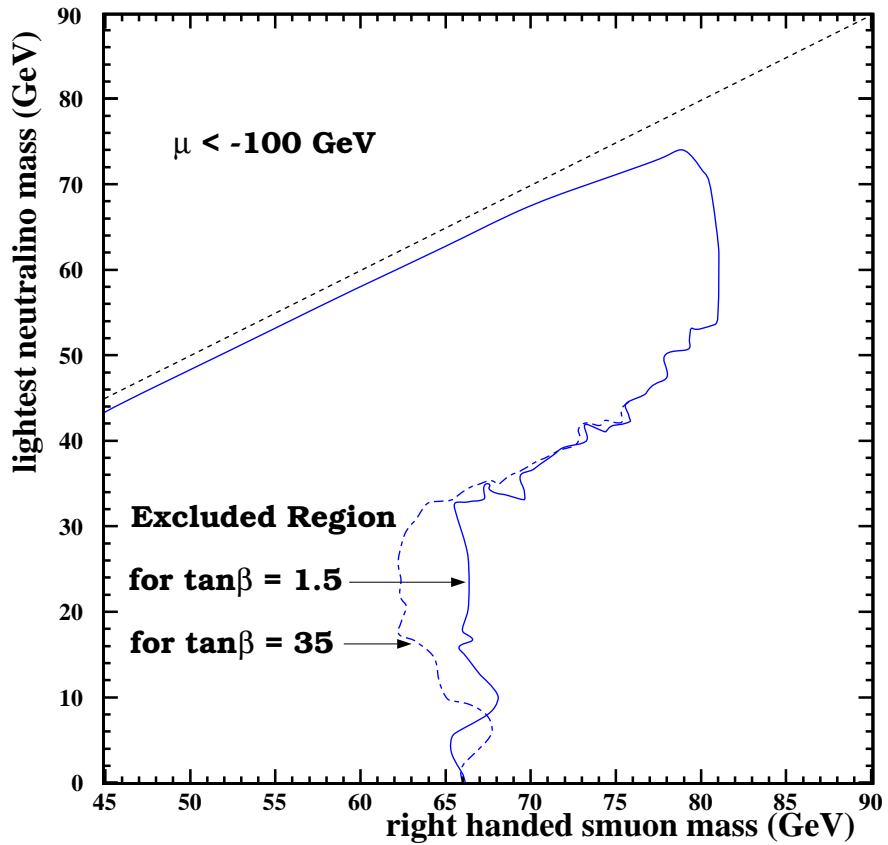
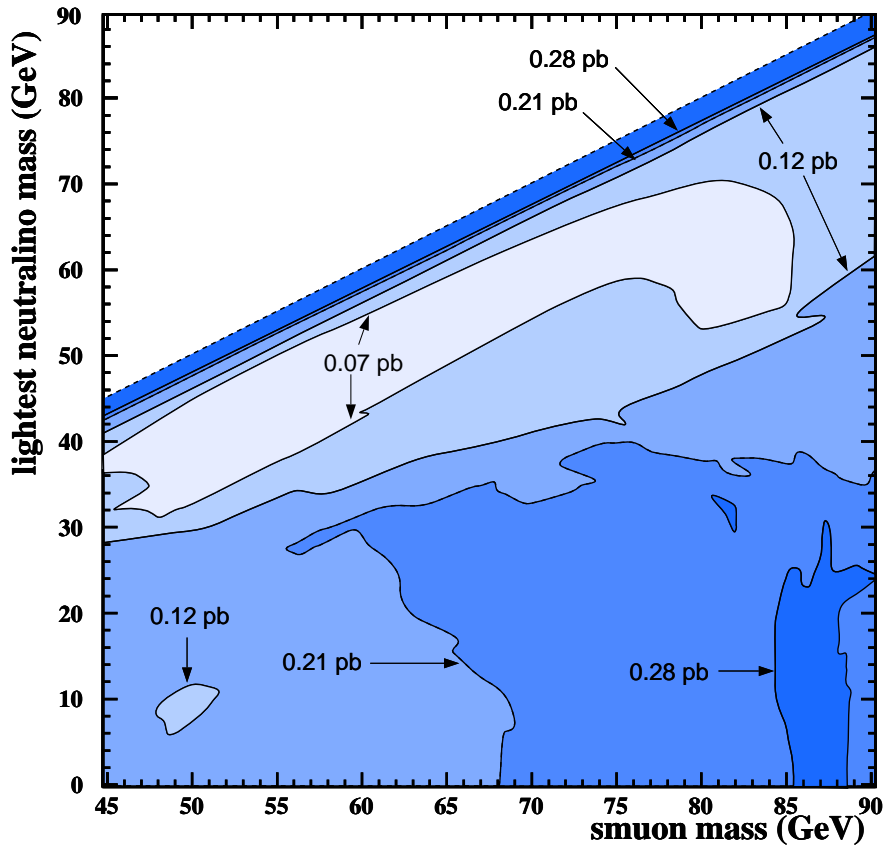
- Visible only if $\Delta m = m(\tilde{\mu}) - m(\tilde{\chi}_1^0) > \text{a few GeV}$.
- Righthanded sfermions are lighter than lefthanded ones!

No signal found !

Smuon Candidate (ALEPH, $\sqrt{s} = 181$ GeV)

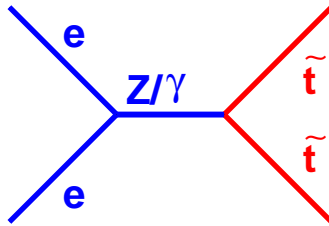


OPAL

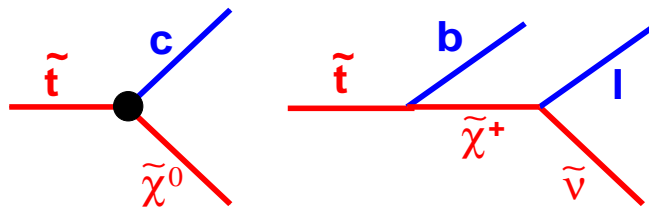


Stop

PRODUCTION:



DECAY:



SIGNATURE:

Two acollinear jets (+ leptons)

BACKGROUNDS:

'two photon': $e^+e^-q\bar{q}$, '4-fermion': $Z\gamma^*$. . .

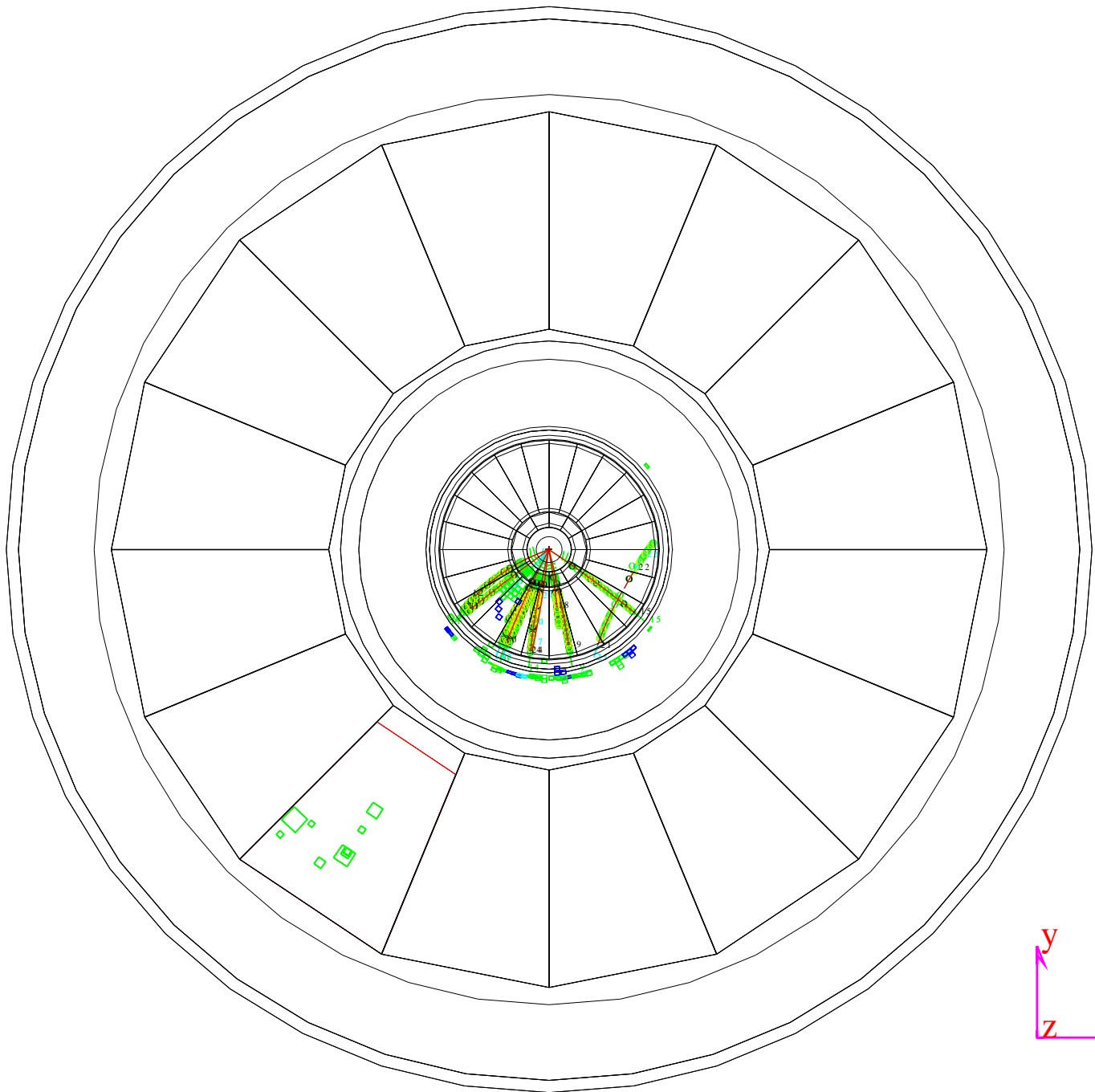
REMARKS:

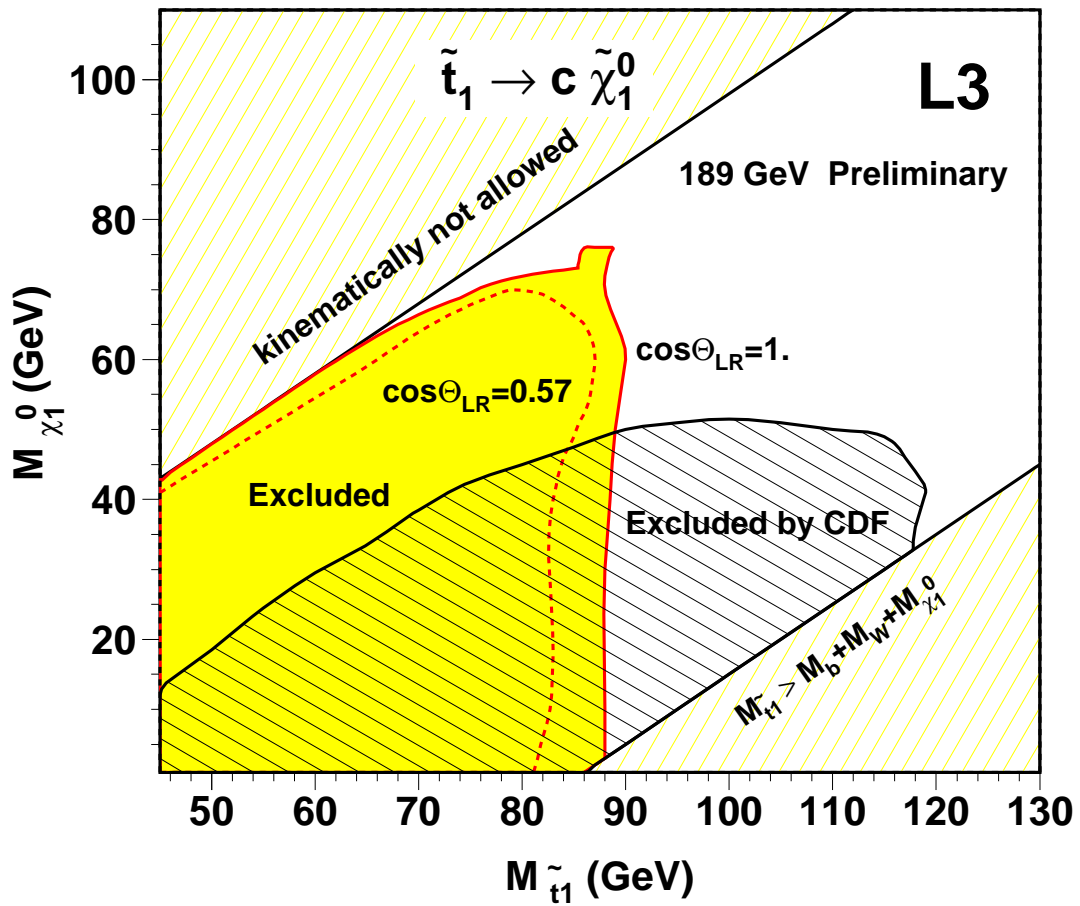
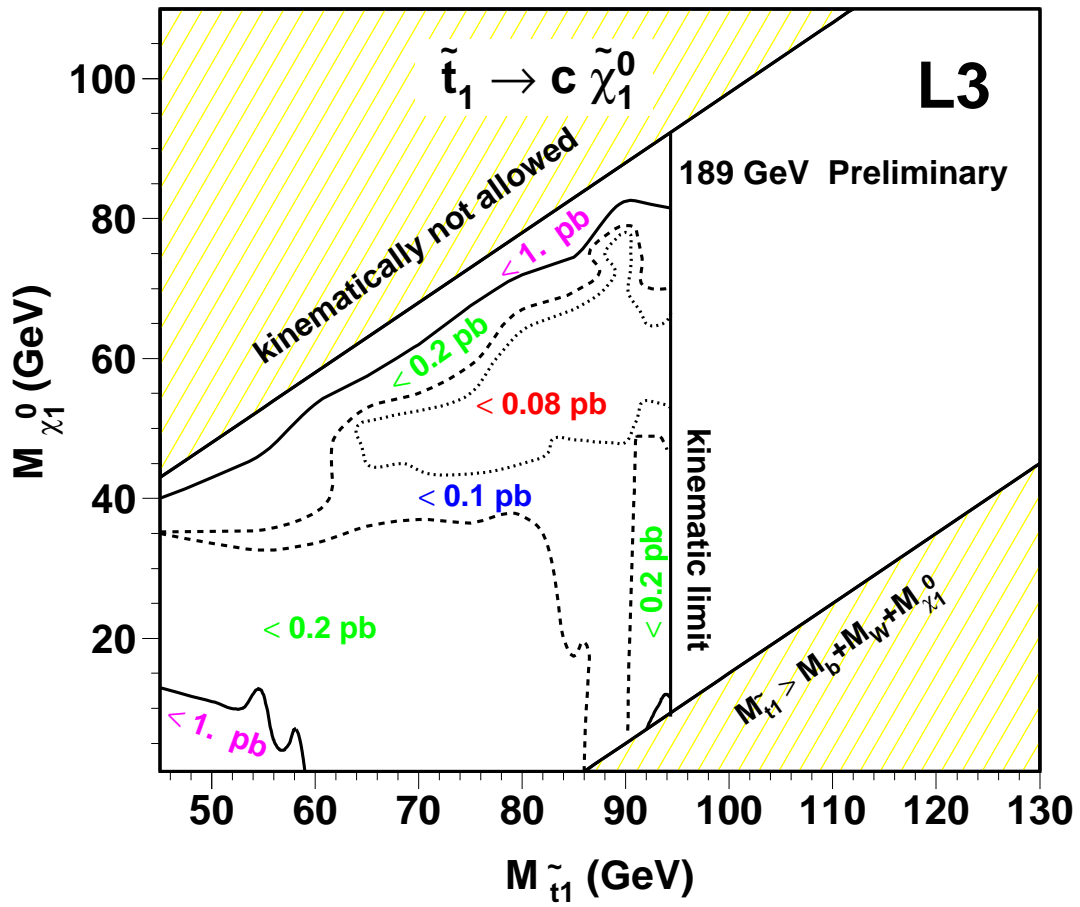
- Visible only if $\Delta m = m(\tilde{t}) - m(\tilde{\chi}_1^0, \tilde{\nu}) > \text{a few GeV}$.
- Mixing: $\tilde{t}_1 = \tilde{t}_L \cos \theta_{LR} + \tilde{t}_R \sin \theta_{LR}$
influences mass and couplings
For $\cos \theta_{LR} = 0.57$ NO coupling to Z!

No signal found !

Stop Candidate (L3, $\sqrt{s} = 183$ GeV)

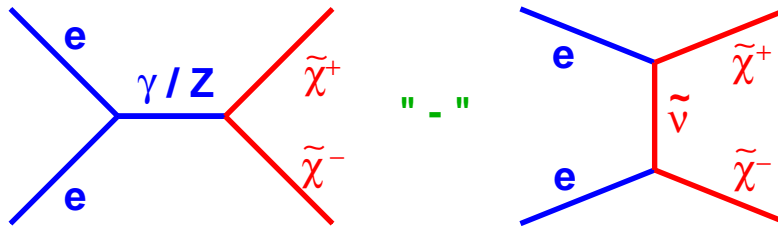
Run # 673109 Event # 3053 Total Energy : 30.64 GeV



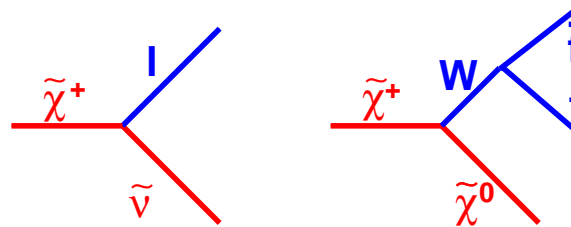


Chargino

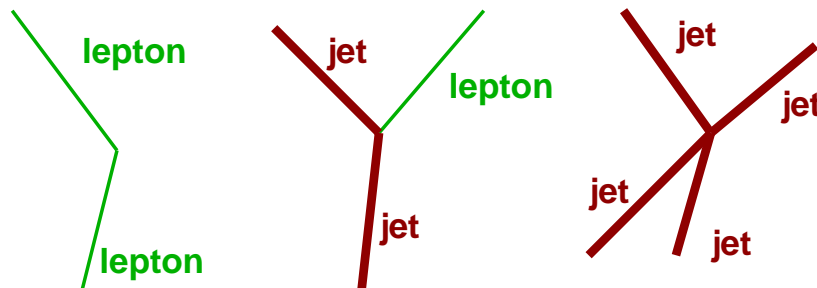
PRODUCTION:



DECAY:



SIGNATURE:



BACKGROUNDS:

'two photon': $e^+e^-f\bar{f}$, '4-fermion': W^+W^- , $Z\gamma^*$. . .

REMARK:

- Visible only if $\Delta m = m(\tilde{\chi}^+) - m(\tilde{\chi}_1^0) > \text{a few GeV}$.

No signal found !

Chargino Candidate (OPAL, $\sqrt{s} = 182$ GeV)

Run: event 8143: 79414

Crk(N= 2 Sump=122.1) Ecal(N= 9 SumE= 51.3)

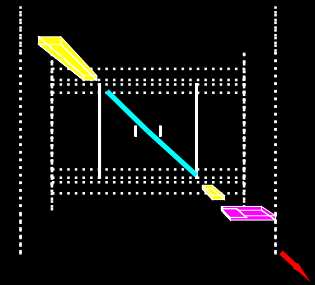
Ebeam 91.000 Vtx (0.00, 0.00, 0.00)

Hcal(N= 2 SumE= 2.8) Muon(N= 1)

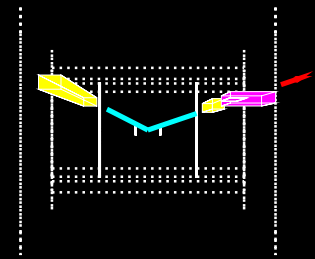


Side view - plane of Thrust axis

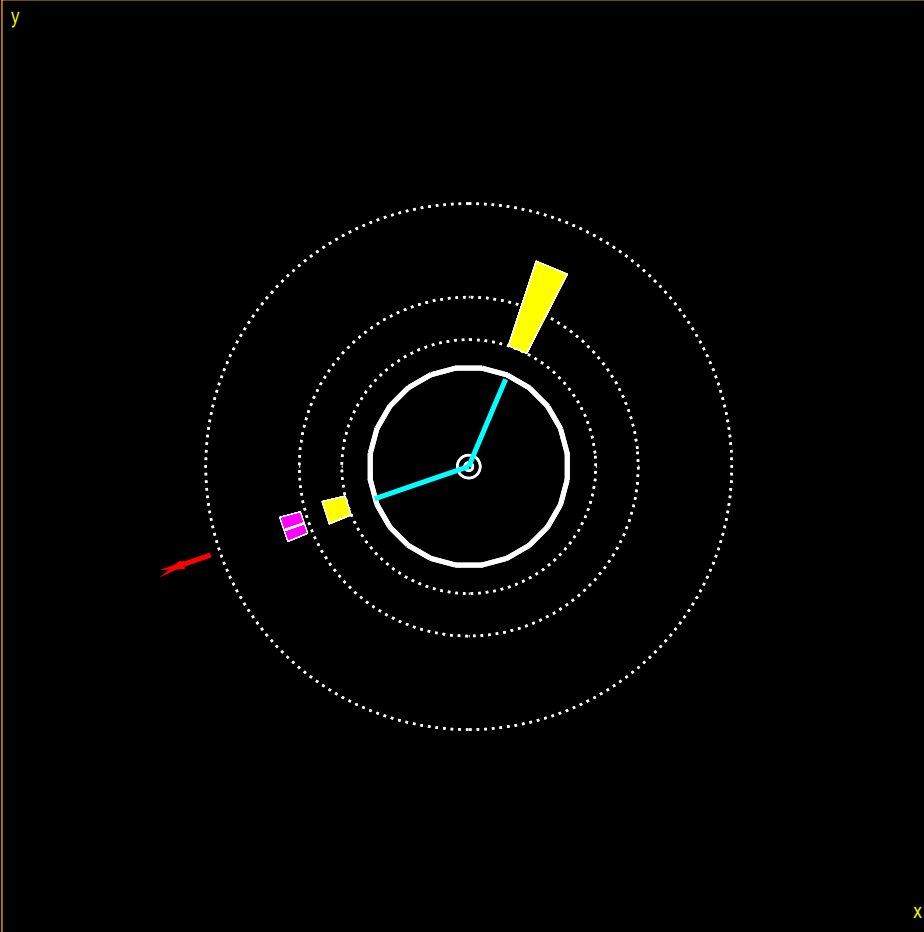
Phi=129.



Phi= 39.



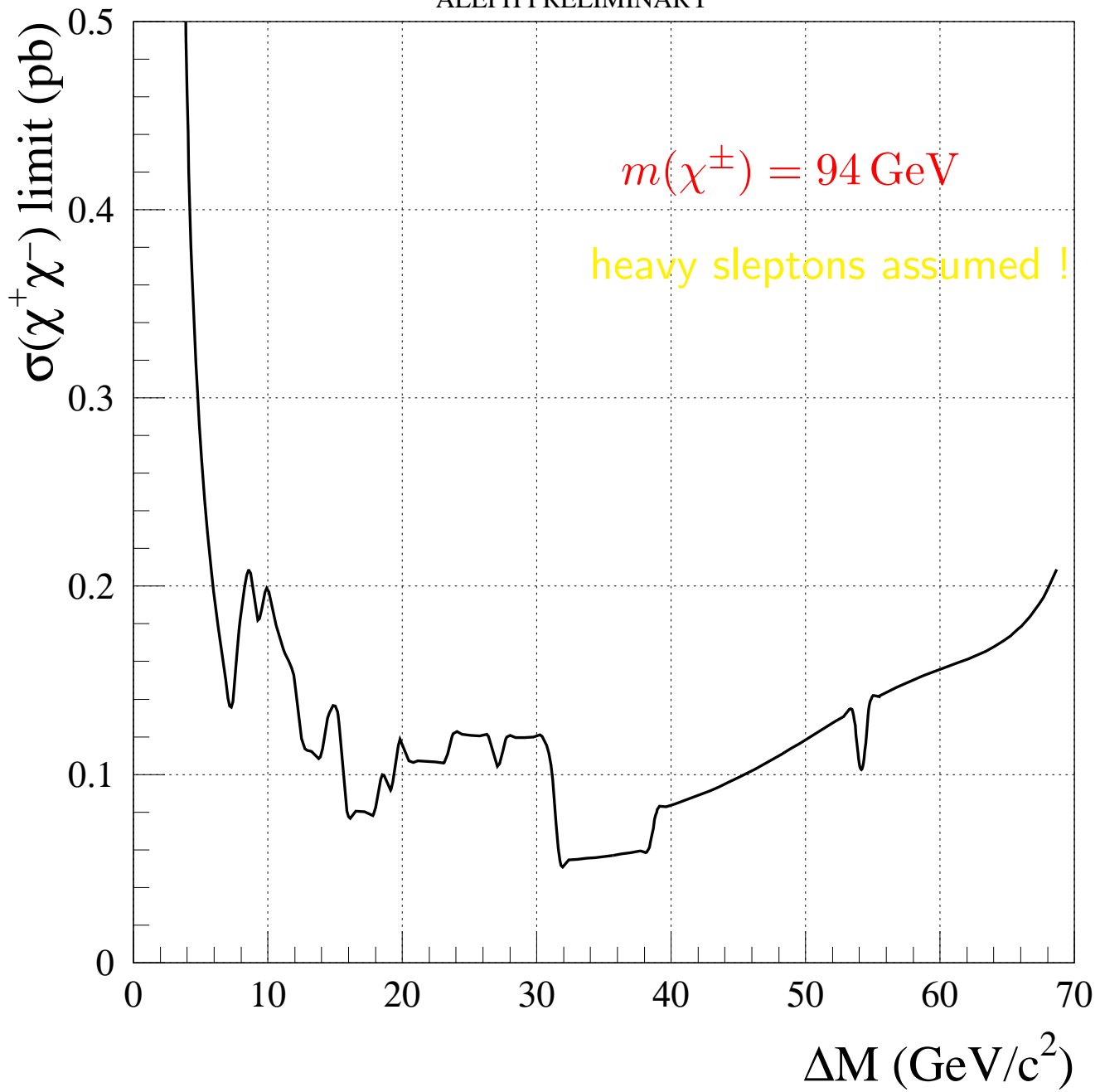
Side view - plane perp. to Thrust



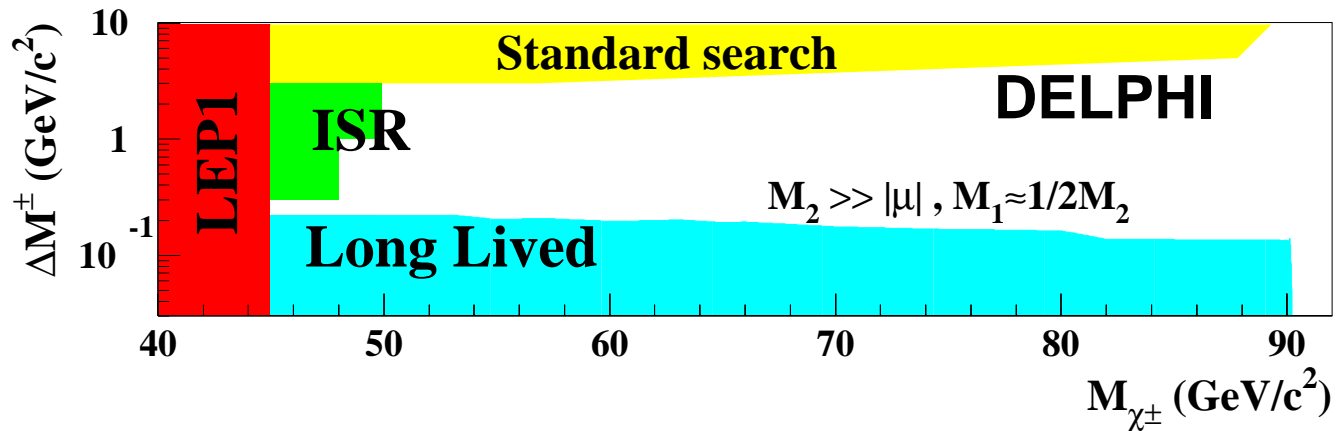
x-y view

ALEPH, 189 GeV

ALEPH PRELIMINARY



Chargino Limits for small ΔM



ISR = Initial state radiation: Photon + soft particles

Long Lived = displaced vertex

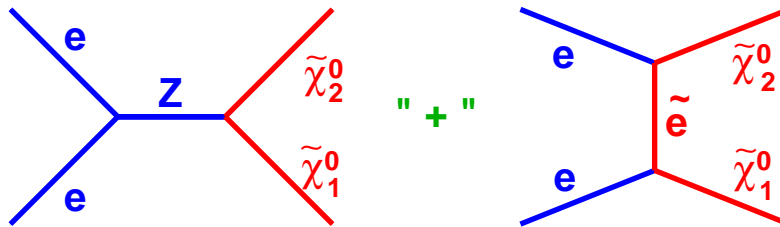
or

stable particle: highly ionizing!

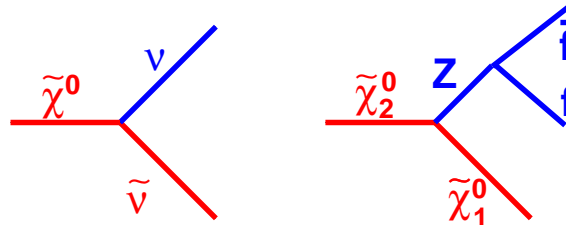
Neutralino

PRODUCTION:

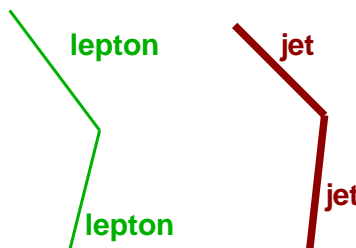
$$e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \text{ invisible!}$$



DECAY:



SIGNATURE:



BACKGROUNDS:

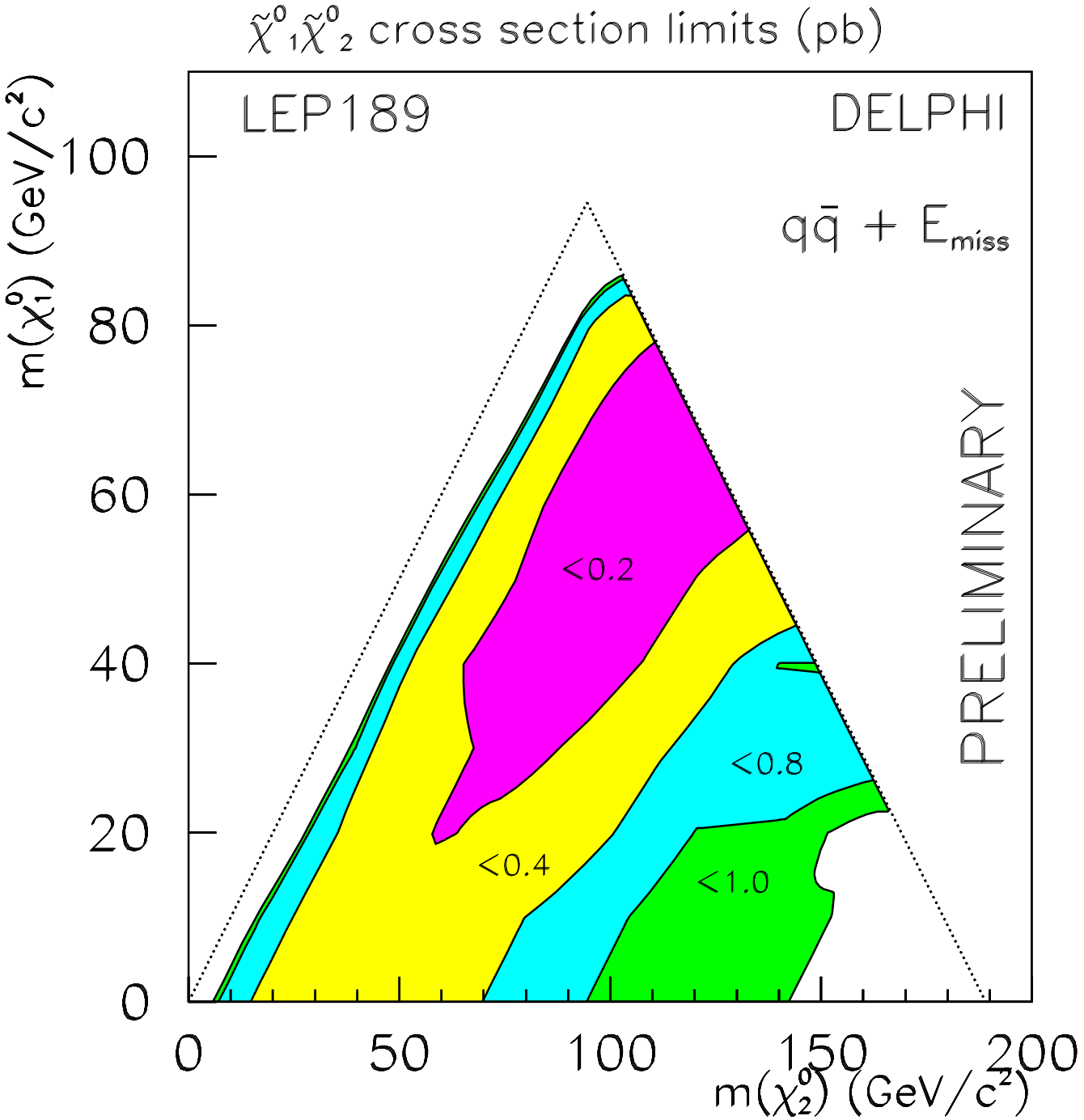
'two photon': $e^+e^- f \bar{f}$, '4-fermion': $ZZ, W^+W^- \dots$

REMARK:

- Visible only if $\Delta m = m(\tilde{\chi}_2^0) - m(\tilde{\chi}_1^0) > \text{a few GeV}$.

No signal found !

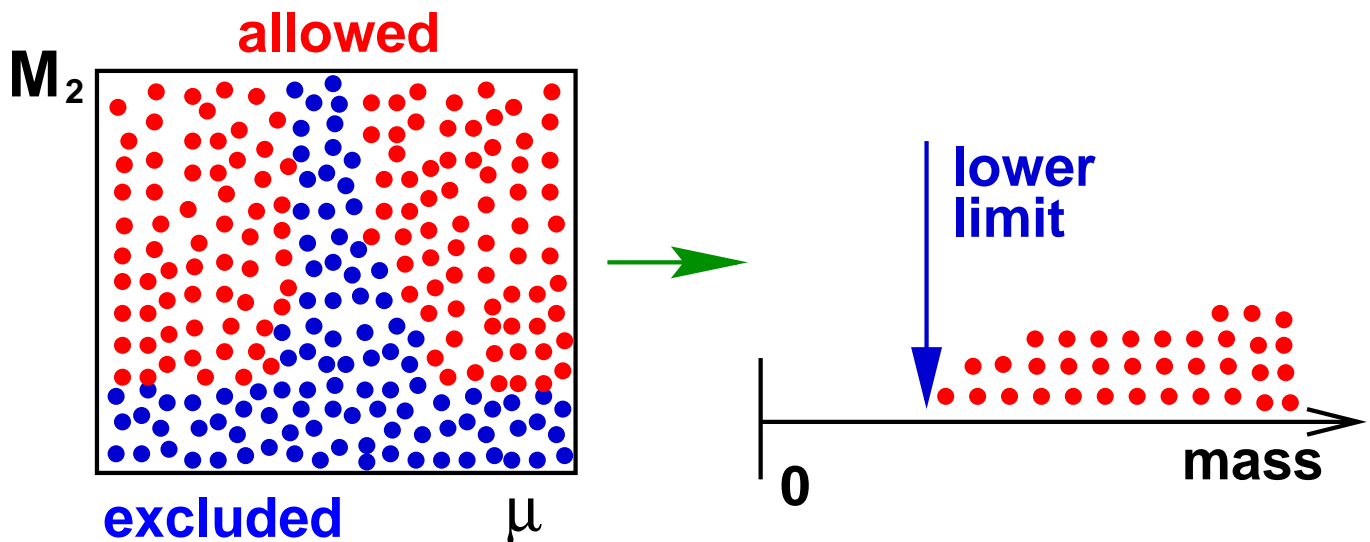
DELPHI, 189 GeV



assuming $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + q\bar{q}$

How to obtain MSSM-6 Limits ?

- Search and calculate experimental limits on xsections, branching fractions . . .
- Calculate excluded SUSY parameter ($M_2, \tan \beta \dots$) regions:
For a given point compare MSSM xsections etc. to the experimental limits.

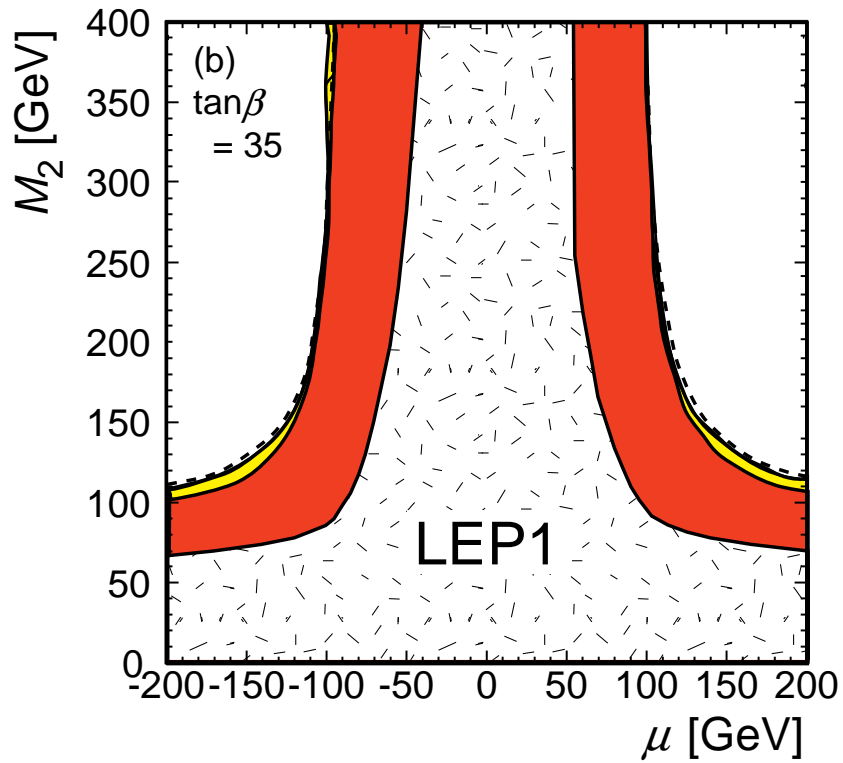
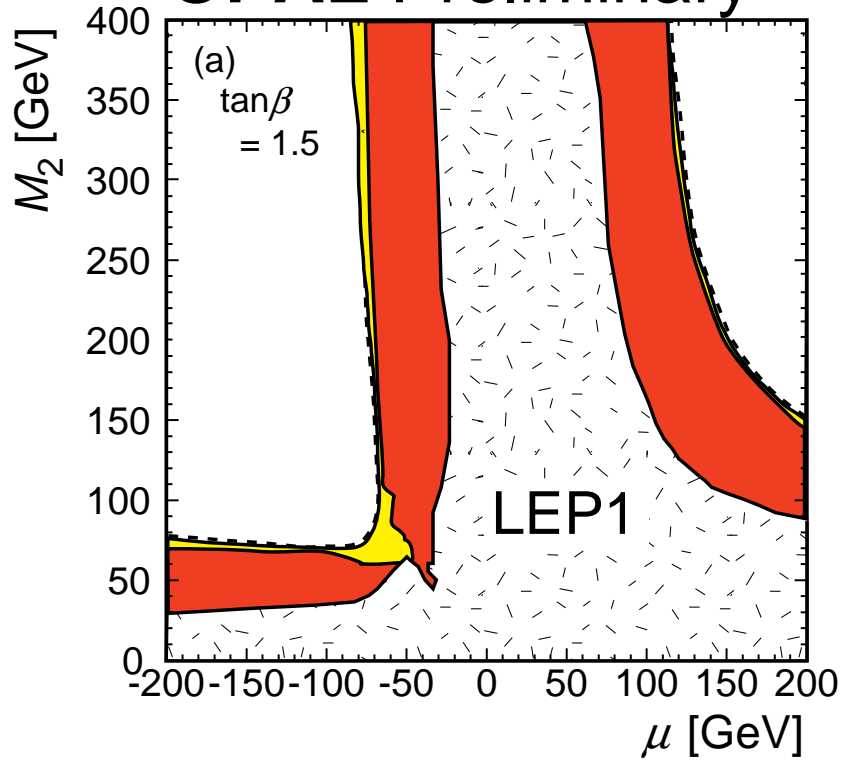


- Determine sparticle mass limits:
Scan through allowed subspace of 6-dim SUSY parameter space and calculate mass values
→ lower mass limit

Note: limit in general better than from direct search in the corresponding channel!

MSSM-6 Limits

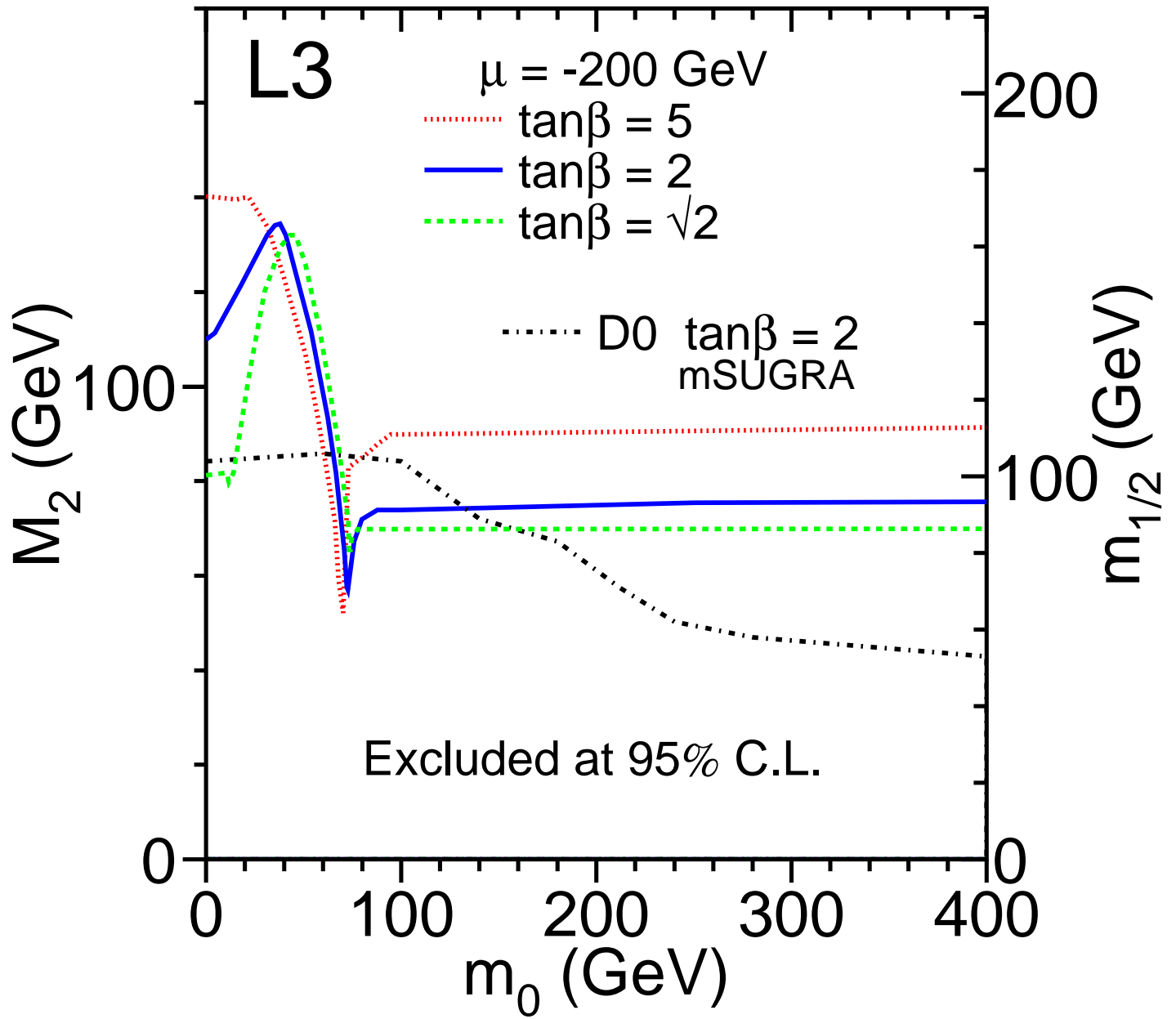
OPAL Preliminary



$m_0 > 500$ GeV

any m_0

MSSM-6 Limits



MSSM-6 Mass Limits

All limits 'unconditional' !, CL = 95%

- Sneutrino $\tilde{\nu}$

$$m > 43 \text{ GeV}$$

- Neutralino χ_1^0

$$m > 32.5 \text{ GeV} \quad (L3, \text{prel.})$$

- Charged Slepton $\tilde{e}_R, \tilde{\mu}_R, (\tilde{\tau}_R)$

$$m > 41 \text{ GeV}$$

- Chargino χ_1^\pm

$$m > 67.7 \text{ GeV} \quad (L3, \text{prel.})$$

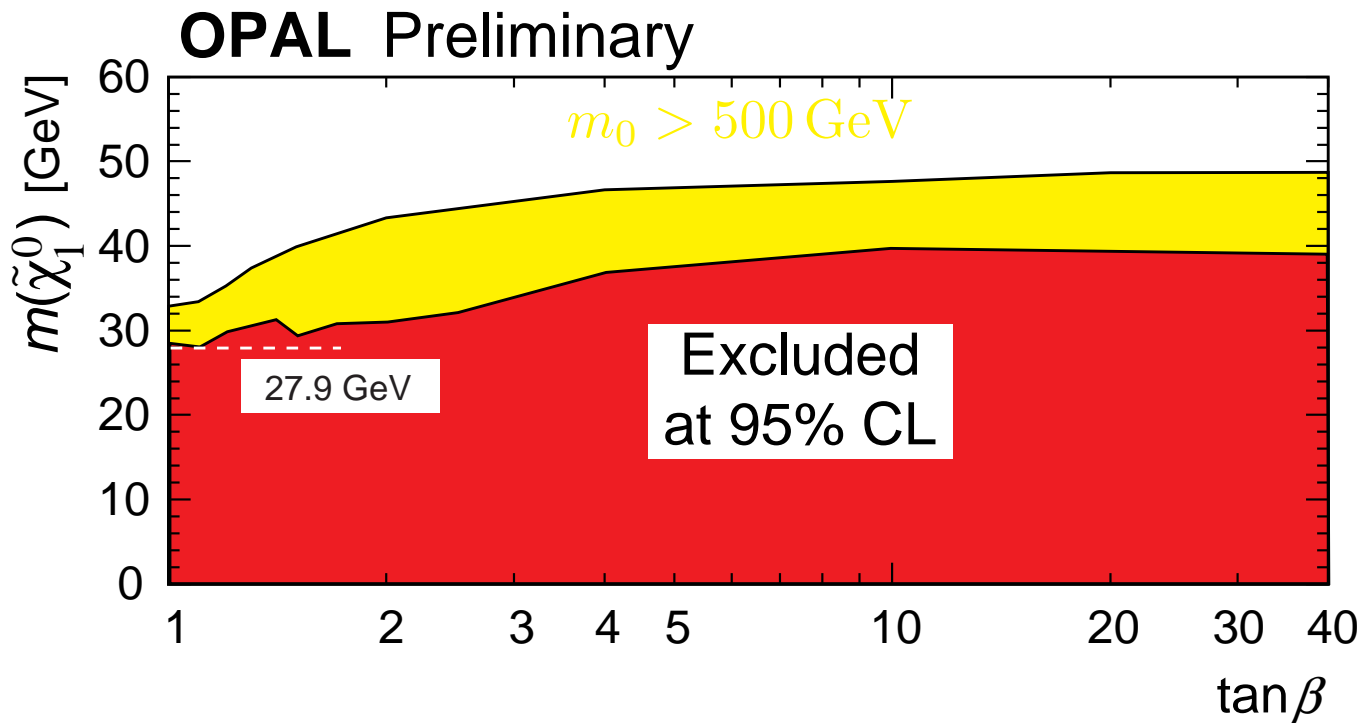
$m(LSP) > 32.5 \text{ GeV}$

??? MSSM-6 parameter space fully investigated ????

Preliminary Gaugino Mass Limits

95% CL

Neutralino:



Aleph	32.3 GeV
Delphi	31.2 GeV
L3	32.5 GeV
Opal	27.9 GeV

Chargino ($M_2 < 2 \text{ TeV}$):

L3	67.7 GeV
Opal	65.1 GeV

Conclusions

- SUSY particles have been searched for intensively at LEP I and LEP II
- Nothing was found yet
- Limits on SUSY parameters, sparticle masses and cross sections have been set
MSSM-6: $LSP \text{ mass} > 32.5 \text{ GeV}$ (prel.)
- The hunt continues:
2 more years of data at $\approx 200 \text{ GeV}$. . .

